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BEFORE THE BOARD OF PATENT APPEALS AND INTERFERENCES

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Application Number: 09/404,826
Filing Date: September 24, 1999
Appellant(s): HAWTHORNE ET AL.

Richard P. Krinsky
For Appellant

EXAMINER'S ANSWER

This is in response to the appeal brief filed March 14, 2006, appealing from the Office action mailed November 1, 2005.

(1) Real Party in Interest

A statement identifying by name the real party in interest is contained in the brief.

(2) Related Appeals and Interferences

The examiner is not aware of any related appeals, interferences, or judicial proceedings which will directly affect or be directly affected by or have a bearing on the Board's decision in the pending appeal.

(3) Status of Claims

The statement of the status of claims contained in the brief is correct.

(4) Status of Amendments After Final

The appellant's statement of the status of amendments after final rejection contained in the brief is correct.

(5) Summary of Claimed Subject Matter

The summary of claimed subject matter contained in the brief is correct.

(6) Grounds of Rejection to be Reviewed on Appeal

The appellant's statement of the grounds of rejection to be reviewed on appeal is correct.

(7) Claims Appendix

The copy of the appealed claims contained in the Appendix to the brief is correct.

(8) Evidence Relied Upon

5,420,883	SWENSEN et al.	5-1995
5,533,695	HEGGESTAD et al.	7-1996

5,620,155	MICHALEK	4-1997
5,785,283	EHRENBERGER et al.	7-1998
5,786,998	NEESON et al.	7-1998
5,848,064	COWAN	12-1998
5,978,718	KULL	11-1999

David C. Coll, et al., "The Communications System Architecture of the North American Advanced Train Control System," August 1990.

Hamid R. Sharif and Edward L. Furman, "Analytical Model for ATCS Inbound RF Channel Throughput," 1991.

The above two non-patent documents were cited by the examiner in the Office action mailed 04/05/2004 as describing details of the communication interfaces within the Advanced Train Control System (ATCS), on which U.S. Patent No. 5,786,998 to Neeson et al. relies. *See, e.g., Neeson et al.*, col. 1, lines 63-66 and col. 22, lines 55-59; (see also Non-final Rejection (04/05/2004) at p. 5.)

(9) Grounds of Rejection

The following ground(s) of rejection are applicable to the appealed claims:

Claims 1-3, 7, 9, 10, and 15-19 are rejected under 35 U.S.C. 103(a) as being unpatentable over U.S. Patent No. 5,786,998 to Neeson et al. in view of U.S. Patent No. 5,533,695 to Heggestad et al. and U.S. Patent No. 5,978,718 to Kull.

Claim 4 is rejected under 35 U.S.C. 103(a) as being unpatentable over Neeson, *Heggestad*, and *Kull*, as applied to claim 1 above, and further in view of U.S. Patent No. 5,848,064 to Cowan.

Claims 20 and 21 are rejected under 35 U.S.C. 103(a) as being unpatentable over Neeson, *Heggestad*, and *Kull*, as applied to claim 1 above, and further in view of U.S. Patent No. 5,420,883 to Swensen et al.

Claims 46-49 are rejected under 35 U.S.C. 103(a) as being unpatentable over Neeson, *Heggestad*, and *Kull*, as applied to claim 1 above, and further in view of U.S. Patent No. 5,785,283 to Ehrenberger et al.

Claim 51 is rejected under 35 U.S.C. 103(a) as being unpatentable over Neeson, *Heggestad*, and *Kull* as applied to claim 1 above, and further in view of U.S. Patent No. 5,620,155 to Michalek.

(10) Response to Argument

Claim 1, Second Paragraph (Appeal Brief at pp. 5-8)

The second paragraph of Appellant's Claim 1 recites,

> determining from the data base the location of the train relative to the track structure and whether the train is within communication range of one of the remote base stations, the determining being made by using location information about the train, information about the track structure and location information about the multiple remote base stations from the data base stored on the computer onboard the train;

See Claim 1.

Appellant's arguments in section I(B)(1) for Claim 1, 2nd paragraph (Appeal Brief at p. 5)

A careful reading of the Office action, (*see* Final Rejection (11/01/2005) at pp. 4-5,) shows that rather than failing to cite a disclosure in Neeson et al. that meets Appellant's "from a database" clause, the examiner conceded, in accordance with the factual analysis set forth in *Graham v. John Deere Co.*, 383 U.S. 1, 148 USPQ 459 (1966), that Neeson et al. does not

expressly disclose the use of a data base. The Office action reflects that Neeson et al. discloses the remaining features the limitation in question, and relies upon the Kull reference as suggesting the use of an onboard database to determine locomotive location relative to track structures and remote base stations. (*see* Final Rejection (11/01/2005) at pp. 4-5.)

Appellant's arguments in section I(B)(2) for Claim 1, 2nd paragraph (Appeal Brief at p. 5)

With regard to Appellant's interpretation of the disclosure in col. 5, lines 16-32 of Neeson et al., the examiner asserts that the half-duplex nature of the MCP restricts the MCP in that it cannot simultaneously receive and transmit messages (as expressly disclosed in the above-cited section of Neeson et al.). In response, the MCP had been designed so that it would not remain stuck in a transmit-only mode, repeatedly attempting to send data packets while the locomotive is out of range. This was done (as disclosed by Neeson et al.) to prevent a possible situation in which the continuously-transmitting MCP could miss important emergency information from the dispatcher. The cited section of the Neeson et al. reference does not, as Appellant suggests, disclose that the ground network must initiate communication. Determining that a base station is out of range is not the same thing as waiting for a base station to initiate communication. Rather, the system of Neeson et al. is an event-driven system that responds to such events as the MCP losing ground contact or exiting the coverage area (corresponding to an ALERTS_EVENT value of LOST_CONTACT) and the MCP regaining ground contact or entering coverage (corresponding to an ALERTS_EVENT value of REG_CONTACT). Upon a LOST_CONTACT event, the system state (ALERT_STATE) changes to one of OOC_IDLE, OOC_CHG_PEND, and OOC_RPT_OUTSTANDING (see Fig. 4), and the appropriate state-dependent procedures (beginning with "S_") are called (see col. 14, line 10, through col. 15, line

34). Upon a REG_CONTACT event, the system state changes to one of CHECK_TABLE, RPT_OUT, and CHG_PEND_RPT_OUT (see Fig. 4).

Appellant's arguments in section I(B)(3) of the Appeal Brief for Claim 1, 2nd paragraph (Appeal Brief at pp. 5-6)

The examiner respectfully submits that if the train and a remote base station are in communication, they are, logically, also in communication range. Thus, even assuming, *arguendo*, that Appellant is correct in that Neeson et al. only discloses determining onboard whether the train and a remote base station are in communication, this is also a determination that the train and the remote base station are in communication range.

Appellant's arguments in section II(B) of the Appeal Brief for Claim 1, 2nd paragraph (Appeal Brief at p. 6)

The examiner respectfully submits that it is precisely because the OBC in Heggestad et al. is continuously provided with location information (from trackside transponders) that the train knows its exact location. Contrary to Appellant's assertion, this does not make it unnecessary for the OBC to establish communication. Rather, the system of Heggestad et al. must establish communication in order to receive authority and profile data. *See*, e.g., *Heggestad* at col. 7, lines 6-20, and col. 9, line 15, through col. 10, line 25.

Appellant's arguments in section III(B) of the Appeal Brief for Claim 1, 2nd paragraph (Appeal Brief at pp. 6-7)

Again, the examiner asserts that a careful reading of the Office action, (*see* Final Rejection (11/01/2005) at pp. 4-5,) shows that rather than failing to cite a disclosure in Neeson et al. that meets Appellant's "from a database" clause, the examiner conceded, in accordance with the factual analysis set forth in *Graham v. John Deere Co.*, that Neeson et al. does not expressly disclose the use of a data base. The Office action reflects that Neeson et al. discloses the

remaining features the limitation in question, and relies upon the Kull reference as suggesting the use of an onboard database to determine locomotive location relative to track structures and remote base stations. (*see* Final Rejection (11/01/2005) at pp. 4-5.)

Appellant's arguments in section IV(B) of the Appeal Brief for Claim 1, 2nd paragraph (Appeal Brief at p. 7)

Neeson et al. describes a system that relies extensively on the ATCS standards. *See*, *e.g.*, *Neeson* at col. 22, lines 55-59 ("[T]he application of the present invention is designed to 'piggy back' on the already existing ABNS and ATCS systems . . . ."); *Id.* at col. 10, lines 55-57 ("[T]he ALERTS application is designed to read Health Reports which conform to the latest ATCS standards."). Heggestad et al., as cited by the examiner, very clearly describes one disadvantage of the ATCS systems. *Heggestad* at col. 2, lines 21-29 ("Both Auer and the ATCS systems, however, require duplicating, in a central office computer, most or all of the vital logic performed at interlockings. This creates the potential for a discrepancy in timing, if not in content, between authorities granted from the central office logic versus those displayed by the wayside signals . . . ."). Heggestad proposes a solution which, among other things, uses fixed profile data and dynamic authority data derived from wayside vital logic and using the on-board computer to merge the fixed and dynamic data. *E.g., Heggestad* at col. 3, lines 29-40. Therefore, the examiner submits that there is ample motivation to combine the teachings of Heggestad with the disclosure of Neeson, and Appellant's arguments otherwise are unfounded.

Appellant's arguments in section V(B) of the Appeal Brief for Claim 1, 2nd paragraph (Appeal Brief at pp. 7-8)

The examiner submits that Kull does not merely teach having information in a database, but rather teaches using the information in a database to determine the location of the train relative to the track structure. For example, of Kull discloses:

> According to instructions contained within its programming code, the computer 240 uses the enumerated signals along with an in comparison to the aforementioned data to determine not only the position that the train occupies on the railway track but also the whereabouts of the upcoming wayside signal device relative to the position of the train. Specifically, the computer 240 determines where the train is located in relation to the track route location data stored in the onboard database.

Kull at col. 9, lines 19-27.

The system of Kull provides the capability to determine whether a locomotive is within communication range (*e.g.*, visual communication) of one of these wayside signal devices in order to facilitate proper operation of the locomotive. *E.g., Id.* at col. 1, lines 14-44. Neeson et al. likewise disclose a railway communications system in which locomotives are controlled through operational status messages. *E.g., Neeson* at col. 8, lines 11-24. Furthermore, Kull provides the advantage of additional warning capabilities based on visual aspects of wayside signal devices in situations where a cab signal is unavailable. *E.g., Kull* at col. 5, lines 1-17.

Claim 1, Third Paragraph (Appeal Brief at pp. 8-11)

The third paragraph of Appellant's Claim 1 recites,

> **establishing** from onboard the train a wireless communication with one of the multiple remote base stations determined to be within communication range;

See Claim 1 (emphasis added).

It should be noted that Appellant attempted to improperly amend claim 1 in the reply filed 01/13/2004, necessitating a rejection under 35 U.S.C. § 112, first paragraph, for failing to comply with the written description requirement:

> Applicant's amendments to claims 1 and 10, replacing "establishing" with "initiating"/"initiating from" do not appear to be directly supported by the originally-filed specification. In particular, the relevant portions of the specification (p. 8, line 19, through p. 9, line 12) discuss **establishing** wireless communication but do not discuss **initiating from onboard the locomotive** such wireless communication apart from the general establishment of such communication.

(Non-Final Rejection (04/05/2005) at pp. 5-6 (emphasis in original).) Appellant responded by amending the claims accordingly:

> Claim 1 has been amended to remove the objectionable language of "initiating." Instead, it now requires "attempting and establishing" from onboard the wireless communication. This is specifically supported in the specification on page 8, lines 24-29.

(Remarks (08/31/2004) at p. 2.) Thus, the examiner emphasizes that claim 1 requires (as written, and in view of the enabling specification) **establishing** from onboard wireless communication and <u>not</u> **initiating** from onboard such communication.

Appellant's arguments in section I(B)(1) of the Appeal Brief for Claim 1, 3rd paragraph (Appeal Brief at p. 8)

As stated above, Appellant's claims do not require <u>initiating</u> communication. Further, Neeson et al. describes establishing communication as discussed throughout this Answer. *See, e.g., Neeson* at col. 3, lines 61-66.

Appellant's arguments in section I(B)(2) of the Appeal Brief for Claim 1, 3rd paragraph (Appeal Brief at pp. 8-9)

The examiner submits that Appellant is mischaracterizing the disclosure of Neeson et al. Appellant's cited section of Neeson et al. (column 7, lines 29-47) merely describes that the

overall system disclosed by Neeson et al. comprises two distinct networks: (1) **the ground network**, which connects the base stations and the front end processor, and (2) **the radio frequency network**, which connects the base stations and the field units. Because the base stations are part of both networks, they provide the interface between the two, *i.e.*, there are ground network connections between the base stations and the front end processor, and there are radio frequency "connections" between the base stations and the field units. This in no way supports Appellant's contention that the ground network or remote stations are in control of communications with the locomotive. Further, Neeson et al. discloses the field unit (locomotive) remaining in radio contact range of the nearest base station as it moves along the track; "Passing off" infers that as a new base station comes within range, radio communication is handled by the new base station that is determined to be within range. *See Neeson* at col. 7, lines 33-47. Executing the handoff requires that the locomotive computer establish onboard wireless communication with the new base station in order to remain in contact. *See Id.*

Appellant's arguments in section I(B)(3) of the Appeal Brief for Claim 1, 3rd paragraph (Appeal Brief at p. 9)

Appellant's cited section of Neeson et al. (column 7, lines 29-47) merely describes that the overall system disclosed by Neeson et al. comprises two distinct networks: (1) **the ground network**, which connects the base stations and the front end processor, and (2) **the radio frequency network**, which connects the base stations and the field units. Because the base stations are part of both networks, they provide the interface between the two, *i.e.*, there are ground network connections between the base stations and the front end processor, and there are radio frequency "connections" between the base stations and the field units. This in no way supports Appellant's contention that the ground network or remote stations are in control of

communications with the locomotive. Further, the cited disclosure, "...in ABNS, communications with locomotives is initiated through the base stations which are in contact with mobile communications packages (MCP) on-board the locomotives," *see Neeson* at col. 2, lines 5-7, merely states that communication is **initiated through** the base stations, and <u>not</u> **initiated by** the base stations, as Appellant has apparently interpreted the passage. The implication of this disclosure is that the system does not communicate directly with the locomotives, but rather uses the base stations as intermediate nodes. This interpretation is further supported by the following disclosure from Neeson et al.:

> The base networking system enables communications contact with the on-board computer 14 on a locomotive via the mobile communications package 12. Speed and control information may thus be sent <u>**from**</u> **the locomotive** 38 through the MCP 12 <u>**through**</u> **the base stations** 52 and 54 <u>**to**</u> **the front end processor** 46 where the information is stored in a particular address allocated to the particular locomotive 38. Likewise, traffic control information and the like may be sent <u>**from**</u> **the dispatcher** 32 through the front end processor 46 <u>**to**</u> **the base stations** 52 and 54 **and** <u>**from there**</u> <u>**to**</u> **the mobile communications package** 12 on board the locomotive 38 to coordinate locomotive movement throughout the railroad system.
>
> *Neeson* at col. 8, lines 11-23 (emphasis added).

Appellant's arguments in section II(B)(1) of the Appeal Brief for Claim 1, 3rd paragraph (Appeal Brief at pp. 10-11)

Appellant's bold accusation of hindsight reasoning is addressed below in the context of the specific factual assertions that Appellant has challenged. (*See* the three sections that immediately follow.)

Appellant's arguments in section II(B)(2) of the Appeal Brief for Claim 1, 3rd paragraph (Appeal Brief at p. 11)

Contrary to Appellant's assertion, the Office action clearly cites col. 5, lines 23-27 of Neeson et al. as describing a pair of frequencies being used for communications between base

stations and the locomotive MCP, one frequency being used for transmissions from the base station to the locomotive (incoming messages), and another is used for transmissions from the locomotive to the base station (outgoing messages). (*See* Final Rejection (11/01/2005) at p. 3.)

Appellant's arguments in section II(B)(3) of the Appeal Brief for Claim 1, 3rd paragraph (Appeal Brief at p. 11)

It should be noted that the factual assertions at issue were first made in the Office action mailed 04/05/2004 in response to Appellant's arguments in the reply filed 01/13/2004. In particular, the examiner maintained (and still maintains) that the two-frequency communication system of Neeson et al. requires the locomotive to initiate all communication at frequency used for outgoing messages because the remote bases stations do not transmit at that frequency and therefore cannot initiate such communication. *See Neeson* at col. 5, lines 23-27. The examiner then stated alternative grounds for maintaining the rejection, specifically, noting:

> [E]ven if Applicant's characterization of the *Neeson et al.* system were correct, *Neeson et al.* still meets the limitations recited in the claims. If a base station initiates communication with a locomotive MCP, then the locomotive must receive, process, and respond to such initiation. In other words, the initial data packet(s) transmitted by the base station must be understood by the MCP as being from a base station within range (otherwise such communication would not be possible/successful), and further, the MCP must acknowledge such initiating with an appropriate response, *i.e.*, the MCP must carry out its own communication initiating procedures to enable communication to take place with the base station. Without providing this basic functionality, the prescribed communication system would not be able to exchange data between the base station and the locomotive MCP. Communication must be established on both ends for the system to function.

(Non-Final Rejection (05/04/2004) at pp. 4-5.) In the same Office action, the examiner cited the Coll and Sharif references, (*see supra* Sec. 8,) explaining that these references describing details of the communication interfaces within the Advanced Train Control System (ATCS), on which U.S. Patent No. 5,786,998 to Neeson et al. relies. *See, e.g., Neeson et al.*, col. 1, lines 63-66 and

col. 22, lines 55-59; (see also Non-final Rejection (04/05/2004) at p. 5.) . The Sharif reference describes the inherent functions that implement the inbound RF channel (the channel from the locomotive to the base station) of the ATCS system used by Neeson et al. *See Neeson et al.*, col. 1, lines 63-66 and col. 22, lines 55-59; *Sharif* at pp. 885-886 (describing the format of the communication packets, the use of the Forward Error Correction protocol, and the channel access protocol—the locomotive waits for the channel to be idle before initiating communication with the base station).

Appellant's arguments in section II(B)(4) of the Appeal Brief for Claim 1, 3rd paragraph (Appeal Brief at p. 11)

The examiner respectfully disagrees with Appellant's characterization of the *Neeson et al.* reference. First, the cited disclosure, "...in ABNS, communications with locomotives is initiated through the base stations which are in contact with mobile communications packages (MCP) on-board the locomotives," *see Neeson* at col. 2, lines 5-7, merely states that communication is **initiated through** the base stations, and not **initiated by** the base stations, as Appellant has apparently interpreted the passage. The implication of this disclosure is that the system does not communicate directly with the locomotives, but rather uses the base stations as intermediate nodes. This interpretation is further supported by the following disclosure from Neeson et al.:

> The base networking system enables communications contact with the on-board computer 14 on a locomotive via the mobile communications package 12. Speed and control information may thus be sent **from the locomotive** 38 through the MCP 12 **through the base stations** 52 and 54 **to the front end processor** 46 where the information is stored in a particular address allocated to the particular locomotive 38. Likewise, traffic control information and the like may be sent **from the dispatcher** 32 through the front end processor 46 **to the base stations** 52 and 54 **and from there to the mobile communications package** 12 on board the locomotive 38 to coordinate locomotive movement throughout the railroad system.

Neeson at col. 8, lines 11-23 (emphasis added). The examiner fully agrees with Appellant that it is improper to "pick and choose from any one reference only so much of it as will support a given position, to the exclusion of other parts necessary to the full appreciation of what such reference suggests to one of ordinary skill in the art." (Appeal Brief at p. 11.) However, the examiner does not agree that it is the Office that failed to read the reference as a whole.

Claim 4 (Appeal Brief at p. 11)

Appellant has incorporated the arguments with respect to claim 1 into the argument for claim 4. Accordingly, the rejection of claim 4 should be affirmed for the reasons given above with respect to claim 1.

Claims 20 and 21 (Appeal Brief at p. 12)

Appellant has incorporated the arguments with respect to claim 1 into the argument for claims 20 and 21. Accordingly, the rejection of claims 20 and 21 should be affirmed for the reasons given above with respect to claim 1.

Claim 51 (Appeal Brief at p. 12)

Appellant has incorporated the arguments with respect to claim 1 into the argument for claim 51. Accordingly, the rejection of claim 51 should be affirmed for the reasons given above with respect to claim 1.

Claims 46-49 (Appeal Brief at pp. 12-13)

The system of Ehrenberger et al. is direct to communications systems in the railway industry, and more particularly, to a system and method for communicating operational status information, such as a defect sensed by a wayside device, for display in the locomotive cab.

Ehrenberger at col. 1, lines 8-13. Ehrenberger et al. discloses as prior art the transmission of track data to control centers and locomotives. *Id.* at col. 1, lines 15-47. Ehrenberger et al. further recognizes a potential problem with locomotive communications systems where a message regarding a defect may not be responded to in a timely manner, possibly resulting in derailment of the locomotive. *Id.* Ehrenberger et al. addresses this problem by advantageously displaying track information onboard the train. *Id.* at col. 3, lines 9-21. Neeson et al. likewise disclose a railway communications system in which locomotives are controlled through operational status messages. *E.g.*, *Neeson* at col. 8, lines 11-24. Accordingly, the examiner maintains that the advantageous improvements to the railway communications system as taught by Ehrenberger et al. would be obvious to combine with the railway communications system of Neeson et al., which lacks these features, thus improving the awareness of train operators of potential hazards.

(11) Related Proceeding(s) Appendix

No decision rendered by a court or the Board is identified by the examiner in the Related Appeals and Interferences section of this examiner's answer.

(12) Text of the Final Rejection

Claims 1-3, 7, 9, 10, and 15-19 are rejected under 35 U.S.C. 103(a) as being unpatentable over U.S. Patent No. 5,786,998 to Neeson et al. in view of U.S. Patent No. 5,533,695 to Heggestad et al. and U.S. Patent No. 5,978,718 to Kull.

As per claim 1, *Neeson et al.* discloses collecting event recorder data, train performance data and track data from onboard in files on the on-board computer (see column 1, line 51 through column 2, line 4; and column 8, lines 11-24); determining onboard if a remote station is within communication range (see column 5, lines 16-32; and column 7, line 63 through column 8, line 3); and initiating from onboard wireless communication between an on-board computer (field unit) and a remote station (base station; see column 7, lines 29-47). *Neeson*

et al. discloses a pair of frequencies being used for communications between base stations and the locomotive MCP. One frequency is used for transmissions from the base station to the locomotive, and another is used for transmissions from the locomotive to the base station (see col. 5, lines 23-27). The locomotive must initiate communication on the base station's receiving frequency because the base station does not transmit data at this frequency and therefore, cannot initiate such communication. Further, if a base station were to initiate communication with a locomotive MCP, then the locomotive must receive, process, and respond to such initiation. In other words, the initial data packet(s) transmitted by the base station must be understood by the MCP as being from a base station within range (otherwise such communication would not be possible/successful), and further, the MCP must acknowledge such initiating with an appropriate response, *i.e.*, the MCP must carry out its own communication initiating procedures to enable communication to take place with the base station. Without providing this basic functionality, the prescribed communication system would not be able to exchange data between the base station and the locomotive MCP. Communication must be established on both ends for the system to function. *Neeson et al.* further disclose determining onboard which of the files are new since last transmission, and transferring the new files to the remote station (see column 5, lines 1-15).

Neeson et al. fails to explicitly disclose determining onboard the location of the train and the location of the next remote station using location information about the train and the remote stations stored on the computer onboard the train. However, *Heggestad et al.* teaches an incremental train control system in which multiple base stations (wayside interface units and wayside control units) are located at various intervals along a railroad track (see, for example, col. 4, line 66, through col. 5, line 13 of *Heggestad et al.*). The onboard computer of a locomotive communicates with the wayside equipment via a radio link (see, for example, col. 5, lines 33-35 of *Heggestad et al.*). Each wayside unit is responsible for the control of trains within a local area covered by each unit (see, for example, col. 6, lines 50-56 of *Heggestad et al.*). The onboard computer, already knowing the exact location of the train, transmits a request for authority to the appropriate nearby wayside unit (see, for example, col. 7, lines 6-20 of *Heggestad et al.*; see also col. 9, line 15, through col. 10, line 25). *Heggestad et al.* further teaches the location of the train and the location of the nearby wayside unit being stored in the computer onboard the train (see, for example, see, for example, col. 7, lines 6-20 of *Heggestad et al.*; see also col. 9, line 15, through col. 10, line 25). Therefore, it would have been obvious to one of ordinary skill in the computer art at the time the invention was made to modify the system of *Neeson et al.* to include such determining the location of the train and the location of the appropriate remote station as per the teachings of *Heggestad et al.* On would be motivated to do so to as part of using a known means of overcoming known deficiencies in the ATCS (Advanced Train Control System) on which *Neeson et al.* is based (see, for example, col. 2, lines 9-29 of *Heggestad et al.*).

Neeson et al. further fails to expressly disclose the computer having a database including track structure information and location information about multiple remote base stations and the determining the location of the train using the database information. However, *Kull* teaches such a database and its use in determining location relative to track structures and remote base stations (see, for example, col. 8, lines 27-35). Therefore, it would have been obvious to one of ordinary skill in the computer art at the time the invention was made to further modify the system of *Neeson et al.* to include such a database and relative location determination as per the teachings of *Kull*. One would be motivated to do so to provide additional warning capabilities to a train operator.

As per claims 2 and 3, *Neeson et al.* discloses determining whether a remote station has updates to be transferred and transferring the updates, including software updates (configuration changes) to the on-board computer (see column 19, lines 49-67). Therefore, for reasons stated above, such claims also would have been obvious.

As per claim 7, *Neeson et al. further* discloses resuming file transfers during subsequent communication sessions after an interruption of wireless communication (see column 14, line 10 through column 15, line 34). Therefore, for reasons stated above, such a claim also would have been obvious.

As per claim 9, *Neeson et al. further* discloses files including data from plural event recorders (intelligent devices) that transfer data to the on-board computer (processing device; see column 4, lines 44-57). Therefore, for reasons stated above, such a claim also would have been obvious.

As per claim 10, *Neeson et al, further* discloses the plural event recorders each connected to a respective on-board computer (intelligent devices have computer processing – "receive and understand" capabilities; see column 2, lines 5-27), initiating wireless communication between the on-board computers (intelligent devices) and the remote station (intelligent devices communicate to the base stations via the processing device), and transferring event recorder data from each of the on-board computers to the remote station (see column 4, line 33 through column 5, line 15). Therefore, for reasons stated above, such a claim also would have been obvious.

As per claim 15, *Neeson et al. further* discloses establishing communication between a remote station (base station) and a home base station (front end processor), and determining what files need to be transferred and transferring the files (see column 8, lines 11-18 and lines 40-44). Therefore, for reasons stated above, such a claim also would have been obvious.

As per claim 16, *Neeson et al. further* discloses transferring operational data for the onboard computer (traffic control information; see column 8, lines 18-24) from the home base station (front end processor) to the remote station (base station). Therefore, for reasons stated above, such a claim also would have been obvious.

As per claims 17 and 18, *Neeson et al. further* discloses transferring operation information of the remote station, including locomotives contacted

(locomotive ID) from the remote station (base station) to the home base station (front end processor; see column 12, lines 50-67). Therefore, for reasons stated above, such claims also would have been obvious.

As per claim 19, *Neeson et al. further* discloses establishing communication between the remote station (base station) and the home base station (front end processor) when requested by a user or according to a schedule (see column 10, lines 19-24). Therefore, for reasons stated above, such a claim also would have been obvious.

Claim 4 is rejected under 35 U.S.C. 103(a) as being unpatentable over Neeson, *Heggestad*, and *Kull*, as applied to claim 1 above, and further in view of U.S. Patent No. 5,848,064 to Cowan.

As per claim 4, Neeson teaches transferring updates to the on-board computer (see column 19, lines 49-67) but fails to teach comparing the version of a file in the on-board computer to the version of a file in the remote station to affect what is transferred. However, Cowan teaches changing the operating software of mobile terminals by detecting a change in a software version identifier in a remote station (host computer) and transferring the change (new version) resulting from the comparison (see column 6, lines 41-51). Therefore, it would have been obvious to one having ordinary skill in the computer art at the time the invention was made to modify the software updating method of Neeson to include the version comparison of Cowan. One would be motivated to do so to ensure that on-board computer's software is kept up-to-date.

Claims 20 and 21 are rejected under 35 U.S.C. 103(a) as being unpatentable over Neeson, *Heggestad*, and *Kull*, as applied to claim 1 above, and further in view of U.S. Patent No. 5,420,883 to Swensen et al.

As per claims 20 and 21, Neeson teaches transferring files between an on-board computer and a remote station (base station; see column 8, lines 11-24) but fails to teach transferring files between remote stations. However, Swensen teaches a hierarchical scheme in which remote stations (trackside radios) retransmit received messages to other, different level, remote stations within a subnet (see column 5, line 64 through column 6, line 29 and Figure 12). Therefore, it would have been obvious to one having ordinary skill in the art at the time the invention was made to modify the Neeson method to include the retransmitting scheme of Swensen. One would be motivated to do so to allow for contacting a train or remote station where a direct link is not possible.

Claims 46-49 are rejected under 35 U.S.C. 103(a) as being unpatentable over Neeson, *Heggestad*, and *Kull*, as applied to claim 1 above, and further in view of U.S. Patent No. 5,785,283 to Ehrenberger et al.

As per claims 46 and 47, Neeson teaches transferring data from a remote station to an on-board computer and from an on-board computer to a remote station (base station; see column 8, lines 11-24) but fails to teach transferring

track data or displaying track data on the train. However, Ehrenberger teaches transferring track data (wayside defects) from a remote station (wayside system) to an on-board computer (see Figure 1) and displaying the track data on the train (see column 3, lines 9 through 21). Therefore, it would have been obvious to one having ordinary skill in the art at the time the invention was made to modify the Neeson method to include transferring track data to the on-board computer and displaying the track data as taught by Ehrenberger and subsequently transferring the track data to another remote station. One would be motivated to do so to keep the train operator informed of potential hazards in the area and to disseminate the information to other train operators in the system.

As per claim 48, in addition to the teachings applied above, Ehrenberger further suggests other types of track data, including status of a highway crossing analyzer (see column 6, lines 52-59). Therefore, it would have been obvious to one having ordinary skill in the art at the time the invention was made to further modify the Neeson method to include track information such as crossing gate position or crossing occupancy status as per the suggestion of Ehrenberger. One would be motivated to do so to communicate a potential highway crossing hazard to the locomotive operator in advance of the train approaching the highway crossing.

As per claim 49, in addition to the teachings applied above, it would have been furthermore obvious to include correlating train performance data with track data, e.g. making a change in speed in response to a detected potential hazard.

Claim 51 is rejected under 35 U.S.C. 103(a) as being unpatentable over Neeson, *Heggestad*, and *Kull* as applied to claim 1 above, and further in view of U.S. Patent No. 5,620,155 to Michalek.

As per claim 51, in addition to the disclosure and teachings applied above, Neeson fails to expressly disclose the use of GPS to determine the location of the train. However, Michalek teaches such a use of GPS to determine the location of a train (see, for example, cols. 6 and 8). Therefore, it would have been obvious to one of ordinary skill in the computer art at the time the invention was made to further modify the Neeson method to include such use of GPS as per the teachings of Michalek. One would be motivated to do so to more accurately determine the location of trains (to within several yards).

For the above reasons, it is believed that the rejections should be sustained.

Respectfully submitted,

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EVIDENCE APPENDIX

David C. Coll, et al., "The Communications System Architecture of the North American Advanced Train Control System," August 1990 (12 pages).

Hamid R. Sharif and Edward L. Furman, "Analytical Model for ATCS Inbound RF Channel Throughput," 1991 (8 pages).

Again, the above two non-patent documents were cited by the examiner in the Office action mailed 04/05/2004 as describing details of the communication interfaces within the Advanced Train Control System (ATCS), on which U.S. Patent No. 5,786,998 to Neeson et al. relies. *See, e.g., Neeson et al.*, col. 1, lines 63-66 and col. 22, lines 55-59; (*see also* Non-final Rejection (04/05/2004) at p. 5; *supra* Section 8.)

The Communications System Architecture of the North American Advanced Train Control System

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Abstract—The Advanced Train Control System (ATCS) Communications System, which provides for the information flow in the North American ATCS, is presented in the context of the overall ATCS plan. The major components and basic operation of ATCS are described. The features and functions of the nodes in the communication system, and their connectivity, are defined. The communications system is based on the OSI model; and the protocols used are described with particular emphasis on the radio data link. Special features of the communications system, including a description of how vehicles are tracked, is included.

I. Introduction

A. Definition and Objectives of the Advanced Train Control System

In 1984, the American Association of Railroads and the Railways Association of Canada founded the Advanced Train Control Systems (ATCS) Project. The purpose of the project was to modernize North American train movement control systems through a cooperative effort of railroads and equipment vendors, with the objective of establishing a unified set of standards for both procedures and equipment; leading to more economical, efficient and safer train movement in North America.

The ATCS Project has been a privately funded project of the two railroad associations that has involved railroad personnel, systems engineers, and potential equipment suppliers in a public open-forum process. It has met its objectives with the definition of a systems architecture that accommodates the flow of all necessary command and control information and with the formulation of open specifications for the components of the system.

The specifications define the performance and interface requirements for ATCS hardware and software. ATCS specifications ensure inter-operability, compatibility, safety, reliability, and functionality of components. They focus on form, fit, and function. They are not intended to be design or manufacturing specifications. They are designed to document the stated requirements of railroad operational and technical authorities and to influence the design of new, compatible equipment without limiting the internal design approaches of individual suppliers. Equipment suppliers are encouraged to produce high performance, low maintenance, and high reliability equipment. They are free to accomplish these objectives and satisfy the requirements of the specifications by means of design techniques and technology which they consider to be cost effective and appropriate. Suppliers and railroads purchasing hardware or software are responsible for ensuring that equipment and its applications satisfy regulatory and safety requirements.

The ATCS, as it has been defined, provides a continent-wide system of train control based on standardized equipment for the first time. Any vehicle outfitted with equipment that satisfies ATCS specifications may be controlled by any appropriately equipped railroad, allowing railways to interact economically and safely, even across the Canada-U.S. border. While implementation of ATCS will represent a massive investment in new equipment, the common specifications mean that the equipment will be available from many vendors who will manufacture to ATCS specifications—providing the railroads with the opportunity to realize significant economies of scale in the implementation.

B. Basic Train Movements and Control

The purpose of the ATCS is to move trains—safely, efficiently, and economically.

Train movement within the ATCS is based on separation of trains through the principle of exclusive occupancy. This is a computer-aided block system in which the access of trains and track forces to any section of track, or block, is strictly controlled by "authorities" issued by a dispatcher. Trains are controlled by "movement authorities," while work crews and associated track vehicles are controlled through "track occupancy permits." A movement authority authorizes movement in one direction on a specified track to a specified point within known limits. No train or track force may move into or within a block without an authority, nor operate beyond a point to which they have been granted an authority. Where necessary, violation of the limits of movement authorities are enforced in ATCS through automatic brake application.

The ATCS is designed to provide the information, communications, and control required to automate and enhance this system of train control.

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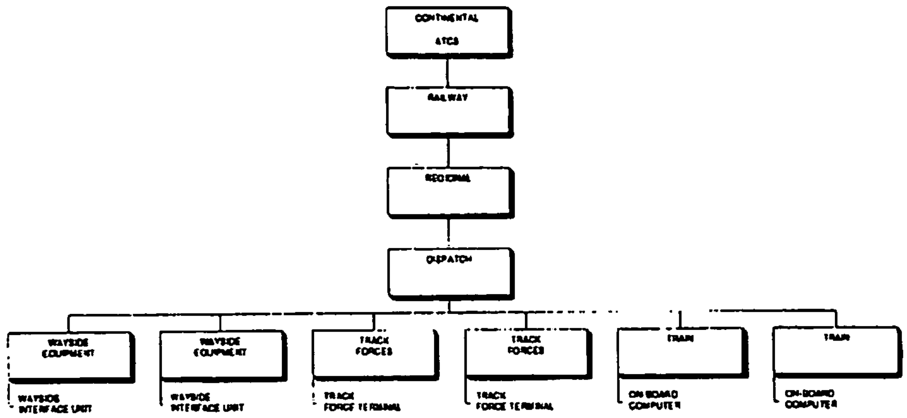

Fig. 1. ATCS system architecture—levels of information processing.

C. Components of the Overall System

The ATCS system architecture is based on an established model of information flow. This flow is shown in Fig. 1, in which six levels of information processing are illustrated: the continental level, the railroad level, the règional level, the dispatch level, and the wayside/mobile level.

The major subsystems in ATCS are: the computer-aided *Dispatch System*; the *Communications System*; *Locomotive Equipment*; *Track Forces Equipment*; and *Wayside Equipment*.

1) The Dispatch System: The dispatch system is responsible for planning the movement of trains; controlling the execution of the general movement plan; monitoring the status of each movement; and reporting operational data to the appropriate ancillary systems.

The key elements of the dispatch system are *dispatching consoles*; the *management system*, which performs nonvital functions and plans daily train movements, plans track occupancies and track work, resolves train conflicts, and manages pacing; the *safety system*, which performs all vital functions and analyzes movement authority requests, issues authorities, issues and releases track occupancy and track work permits, issues track condition notices, tracks train movements and work gangs and track occupancies, controls routing, handles ATCS messages, and maintains system time; the *communications system interfaces*; and the *corporate management information systems interface*. The dispatch system includes dispatch control logic applications software and data bases describing such information as route configurations, train locations, and outstanding authorities (train movement authorizations).

2) The Communications System: The communications system consists of a network of nodes and links to provide communications between the dispatcher and locomotives, track forces, and wayside devices as described in Section II.

3) Locomotive Equipment: The locomotive equipment comprises a data radio and communications package, an onboard computer, locomotive display, brake and throttle controls, odometers, and a transponder interrogator.

Transponders, which are buried in the roadbed, provide coded information to interrogators mounted on the underside of locomotives. The interrogator radiates a radio signal which is inductively coupled to the transponder, powering it and enabling it to transmit its coded identification information back to the interrogator. The interrogator transmits energy at 200 kHz and the data are transmitted by the transponder at 27 MHz.

The transponders are packaged so as to be impervious to moisture, insects, oil, grease, fuel, common corrosives, and ultraviolet radiation. They must be less than 18.5 in × 8 in × 1.5 in in size and have an operating life of 15 a. They may be mounted between the rails or buried in the ballast. They are designed to work through up to 5 in of salt water or 2 in of salt mud.

Transponder data are coded in a 64-b message frame, comprising a synchronizing header (7 b), transponder type (4 b), and railroad identification (36 b), followed by a 17-b cyclic redundancy check in accordance with the DIGITRAC transponder specifications provided by Dynamic Sciences, Inc. The transponder transmits its message as long as it is receiving energizing radiation from an interrogator using differential phase shift keying of a 50-kHz data subcarrier whose amplitude modulates a carrier at 27.255 MHz.

The system is designed to provide a minimum of eight complete data frames to an interrogator when it is crossing a transponder from either direction at speeds up to 130 mi/h. At the same time, the system is designed to avoid energizing transponders on parallel tracks within 12.5 ft.

The locomotive on-board computer (OBC) executes a number of functions that include movement authority enforcement and management; management of data bases describing track segments, interlocks, sidings, train characteristics, the locomotive consist (i.e., its make-up), the car consist, ATCS territory levels, parallel lines, transponders, wayside devices, mileposts, communications coverage, grade crossings, highway crossings, dispatcher change points, track conditions, and track work protection; location systems management; emergency management; wayside device interaction management; test management; message routing; pacing management; train

handling management; and train crew and track force interaction management.

4) Track forces: Track forces are maintenance and construction crews and other nonlocomotive entities occupying the track. They are able to communicate with dispatchers and ATCS data bases through a track forces data terminal consisting of an RF antenna, an ATCS mobile communications package and an ATCS auxiliary terminal.

5) Wayside Devices: The ATCS field system consists of wayside interface units (WIU), controllable and noncontrollable devices. The WIU provides an interface between existing field devices and the ATCS Communications System via Mobile Communication Packages (Section III-D).

Controllable devices are directly controllable by the central dispatch, an individual locomotive, or authorized employees. They include power operated switches, movable bridges, railway crossings at grade, hand operated switches including switch point detection, and highway grade crossing warning system monitors and controls.

Noncontrollable devices include occupancy detection devices, intrusion detection devices, train defect detectors, track integrity indicators, and route integrity indicators. Field systems interact with the other ATCS entities to provide in a locomotive or at the dispatch indications of the position and status of a hand operated switch; the results of a train inspection by wayside defect detectors including high/wide load, dragging equipment, hot box, hot wheel, broken wheel, loose wheel, wheel impact, and other defects; the status of highway grade crossing warning systems; track integrity and conditions; route integrity, including derails, moveable bridges, spring switches, slide detectors, bridge fire detectors, high water detectors, wind detectors, temperature detectors, railroad crossing at grade, and other systems. They can accept control of power switches, wayside signals, and switch heaters (snow melters), and provide indications of their status and position.

D. Basic Train Operations

The management of train operations depends on complete knowledge of the location and status of all of the elements that make up the railroad, including trains, tracks, wayside devices, and track forces. In addition to this knowledge, train control requires complete specification of the steps to be taken to carry out any operation under all circumstances.

Knowledge of train location is provided by the interrogation of transponders buried between the tracks by each train as it moves, and the communication of this data to the dispatcher.

The steps involved in each operation in train movement were meticulously compiled as part of the ATCS design process. The descriptions were called "control flows" and they defined the "stimulus-response" behavior of the various elements of the ATCS that resulted in the execution of each and every operation. They were, in effect, the algorithms by which train operations were governed. The control flows, in turn, defined the information that was required for every operation, providing the basis for the identification of the communications that occurred in the ATCS.

Actual control is exercised via message transmission through the ATCS Communications System, in conjunction with the appropriate rules, regulations, and operating procedures.

TABLE I
TRIP PLAN FILE

Train and locomotive characteristics
train symbols
train type
locomotive restrictions
equipment restrictions
commodity restrictions
number of units and horsepower
loads
gross tons
empties
length
weight profile
Route characteristics
milepost limits of each segment
grade
location of curves and curvature
track configuration
civil speed allowance
speeds associated with turnouts and interlockings
speed restriction
reason for speed restriction
Hazardous materials location in train
Switch locations and ID's
Limits of data communications coverage
Transponder locations (including distance between transponders)

Before a train leaves its initial terminal, a trip plan file containing the information defined in Table I, is downloaded from the dispatcher to the locomotive computer. The data in that file are sufficient to allow the locomotive computer to calculate the braking characteristics of the train and to predict its speed at every point on its trip.

After the train, route data, and the track and route characteristics file are downloaded to the locomotive computer, the dispatcher establishes the movement authorities to be granted to the train and, after they are validated by the route and block locking logic in the dispatch computer, they are transmitted to the locomotive computer.

During the trip, on-board sensors provide the locomotive computer with the train speed, throttle setting, brake setting, acceleration rate, and locomotive health data. As the train progresses, the locomotive computer determines the train location with readings from axle-mounted odometers, with checks provided by data acquired by the transponder interrogator from transponders buried in the roadbed. The location data are used by the on-board logic to determine the appropriate limits of authority, speed restrictions, pacing, and other functions that depend on location. The locomotive computer continuously monitors whether the train is going too fast to slow down or stop at an upcoming authority limit or speed restriction and, if it is, warns the engineman. If the engineman does not act the OBC will initiate an enforcement request to the locomotive brake control system. If an authority limit is passed, it initiates an emergency stop.

Violations of speed restrictions, limits of authority, and emergency brake applications are reported to the dispatch system; and the locomotive receives operational status messages from wayside devices and defective equipment detectors.

E. Basic Messaging

Information is transmitted through the ATCS communications system in *messages* sent between two ATCS applications

TABLE II
MESSAGE FUNCTIONS

Function	Function Name
0	Reserved
1	Railroad Specific Function
2	Manufacturer Specific Functions
3	Databases
4	Test and Diagnostic Information
5	Sensor Monitoring Information
6	Train Location, Movement and Authority Information
7	Train Schedules and Lineups
8	Switch Monitoring and Control Information
9	Wayside device Monitoring and Control
10	Track Forces Movement Control and Status
11	Emergency Reporting
12	Local System (Intra Vehicle Messages)
13	Crew and Personnel Information
14	Car Location Information
15	Free Form Text
16	Work Reporting
17	Mobile Communications Package Control
18	Weather
60 - 79	Railroad Specific Functions
80 - 99	Manufacturer Specific Functions
106	Protocol Information
107	Data System Command/Control Information

TABLE III
MESSAGE TYPES

TYPE NUMBER	TYPE
0	Control information requiring a session
1	Query information
2	Status information
3	Commands not requiring a session
4	General information

or upper layer protocol entities. For example, the dispatch system is continuously aware of the location of every train since each locomotive computer transmits a location message to the dispatch system periodically, with corrections transmitted each time a transponder is passed; periodically when in communications coverage; whenever communications coverage areas are entered or left; and, whenever requested to do so. All messages are numbered and their formats are carefully defined. Message numbers have three parts: function, type, and specifier indicating the particular message of each function and type.

The ATCS message functions are given in Table II, and the types of messages are shown in Table III.

Every message is identified by a label derived from the message number as

$$\text{label} = 512 \cdot \text{number} + 64 \cdot \text{type} + \text{specifier}.$$

Messages are assigned priorities indicating the timeliness of delivery required. Messages are further classified as *vital* or *nonvital*. Vital messages require special protection from transmission errors and delivery to the incorrect destination. A cyclic redundancy check is calculated on the address length, address, facility length, facility, and text fields of each packet of a vital message, and appended to each packet of the message.

Messages are made up of *objects*, which in turn are made up of *fields* of various data types. For example, Object Number 2 is the ROAD/LINE/TRACK Object. It contains bit field data, and its bit length is 24. The fields: ROAD (12 b), LINE (8 b) and TRACK (4 b) indicate the owning railroad, the line on that railroad and the track on that line, respectively. Similarly, Object Number 3 is the MILEPOST Object, a 24-b

TABLE IV
DESCRIPTION OF TRACK SEGMENT DATA OBJECT

NAME	OBJECT TYPE	#	LENGTH
TRACK ID	ROAD/LINE/TRACK	2	24
MILEPOST A	MILEPOST	3	24
MILEPOST B	MILEPOST	3	24
CURVE	CURVATURE	6	16
GRADE	GRADE	6	8
SPEED LIMIT	SPEED	1	8

TABLE V
LOCATION REPORT MESSAGE

MESSAGE NUMBER:	6.2.1	
MESSAGE NAME:	LOCATION REPORT	
FREQ OF OCCURRENCE:	Unspecified	
SOURCE:	LLOC (Location System Manager entity in the Locomotive Computer)	
DESTINATION:	DLOC/ANY(Location System Manager entity in the Dispatch Computer, or any legitimate destination)	
VITAL:	T	Yes, this message is vital
MODE:	1	
PRIORITY LEVEL:	2	
SESSION:	F	No
MESSAGE LABEL:	3201	
MESSAGE RESPONSE:	MESSAGE NUMBER	
REQUIRED/OPTIONAL:	Unspecified	
DESCRIPTION:		

This message is used by the OBC (On Board Computer) to report its current location, speed and limits of authority. Limits of authority shall reflect the maximum limits authorized for the train and may span more than one MA (Movement Authority)

POS	OBJECT NAME	OBJECT TYPE	NUM	DATA TYPE	LEN
1	DESTINATION	NETWORK ADDR	20	BIT FIELD	64
2	TIME GENERATED	TIME/DATE	22	BIT FIELD	32
3	CURRENT LOCATION	LOCATION	4	BIT FIELD	48
4	CURRENT SPEED	SPEED IN MPH	1	BINARY SIGNED	8
5	AUTHORITY START	LOCATION	4	BIT FIELD	48
6	AUTHORITY END LOC	LOCATION	4	BIT FIELD	48
7	TIME GENERATED	TIME/DATE	22	BIT FIELD	32
8	CURRENT LOCATION	LOCATION	4	BIT FIELD	48
9	CURRENT SPEED	SPEED IN MPH	1	BINARY SIGNED	8
10	AUTHORITY START	LOCATION	4	BIT FIELD	48
11	AUTHORITY END LOC	LOCATION	4	BIT FIELD	48

TOTAL BIT LENGTH: MIN 432 MAX 432

TABLE VI
ATCS DIAGRAM PACKET FORMAT

OCTET	CONTENTS
1	Q D 1 0 P P P A
2	LOGICAL CHANNEL NUMBER
3	SEND PACKET SEQUENCE NUMBER P(S)
4	RECEIVE PACKET SEQUENCE NUMBER P(R)
5	SOURCE ADDRESS LENGTH DEST ADDRESS LENGTH
	1 0 1 0 1 0 1 0
6	DESTINATION ADDRESS OCTET 1
7	DESTINATION ADDRESS OCTET 2
8	DESTINATION ADDRESS OCTET 3
9	DESTINATION ADDRESS OCTET 4
10	DESTINATION ADDRESS OCTET 6
11	SOURCE ADDRESS OCTET 1
12	SOURCE ADDRESS OCTET 2
13	SOURCE ADDRESS OCTET 3
14	SOURCE ADDRESS OCTET 4
15	SOURCE ADDRESS OCTET 5
16	FACILITY LENGTH (NORMALLY 0'S)
	FACILITY FIELD (NORMALLY NOT PRESENT)
17-N	USER DATA (128 OCTETS MAXIMUM)

binary data object describing the position of a milepost in 5-ft increments. The concatenation of a ROAD/LINE/TRACK object and a MILEPOST object form the 48-b field of the LOCATION Object.

Objects may include several subobjects. For example, Object Number 26, TRACK SEGMENT DATA, is a bit field 104 b long that contains the objects shown in Table IV.

Complete messages are defined in terms of fields defining their number, label, name, source, destination, vitality, mode, priority, session, response, and contents. A typical message, the LOCATION REPORT, is shown in Table V.

Datagram packets have the format shown in Table VI. Ser-

TABLE VII
ATCS DATAGRAM SERVICE SIGNAL PACKET FORMAT

OCTET	CONTENTS
1	Q D 1 0 P P P A
2	LOGICAL CHANNEL GROUP
3	SEND PACKET SEQUENCE NUMBER P(S)
4	RECEIVE PACKET SEQUENCE NUMBER P(R)
5	SOURCE ADDRESS LENGTH DEST ADDRESS LENGTH 1 0 1 0 1 0 1 0
6	DESTINATION ADDRESS OCTET 1
7	DESTINATION ADDRESS OCTET 2
8	DESTINATION ADDRESS OCTET 3
9	DESTINATION ADDRESS OCTET 4
10	DESTINATION ADDRESS OCTET 5
11	SOURCE ADDRESS OCTET 1
12	SOURCE ADDRESS OCTET 2
13	SOURCE ADDRESS OCTET 3
14	SOURCE ADDRESS OCTET 4
15	SOURCE ADDRESS OCTET 5
16	DATAGRAM IDENTIFICATION OCTET 1
17	DATAGRAM IDENTIFICATION OCTET 2
18	CAUSE FIELD
19	DIAGNOSTIC FIELD
20-35	NETWORK INFORMATION (16 OCTETS MAXIMUM)

TABLE VIII
TRANSPORT LAYER HEADER

Octet 1	Bits 2-8	Message Number
	Bit 1 More Bit (1 on last packet of a message)	
Octet 2	Bits 2-8	Part Number (Packet position within message)
	Bit 1 End-to-end Acknowledge Request Bit	
Octet 3	Bits 2-8	Message Length (in packets)
	Bit 1 Vital Bit (1 in a vital message, vital CRC transmitted in last 4 octets of the packet text)	
Octets 4 and 5		Label Field

TABLE IX
TRANSMISSION MODES

MODE	NAME	EFFECTS
0	Broadcast Mode	No acknowledgements or service signals.
1	Normal Mode	RF acknowledgements are used and service signals on the status of packets are obtained from the network.
2	Database Mode	No link acknowledgements or service signals, but end-to-end acknowledgements are used.
3	Assurance Mode	Link and end-to-end acknowledgements are used.
4	Special Emergency	Five copies are generated and end-to-end acknowledgements used.

vice signal packets have the format shown in Table VII. The bits within Octet 1 of each packet are defined as QD10PPPA, where:

- *Q* indicates a service signal and is set to 0 on all originate traffic,
- *D* indicates that a service signal is required from the network back to the originator indicating whether the packet successfully traversed the RF link,
- *PPP* is the priority of the message,
- *A* is the ARQ disable bit.

Octets 2, 3, and 4 are not used by ATCS. They are set to zero on all originate traffic and ignored on all receive traffic.

The Transport Layer Header occupies the first four octets of the packet text. They are defined in Table VIII. The transmission modes are defined in Table IX.

II. Overview of the ATCS Communications System

A. The Communications System

ATCS Communications System users are grouped as:

1) host applications: dispatch and MIS systems; network applications;
2) locomotive applications;
3) radio and wireline-connected wayside devices;
4) track forces and mobiles, other than locomotives.

The ATCS Communications System architecture is driven by the requirements of these users and the information flows. The ISO seven-layer OSI model forms the basis for the architecture, while the mobile data radio technology used to provide the data path to the vehicles has had a major impact on the detailed implementation.

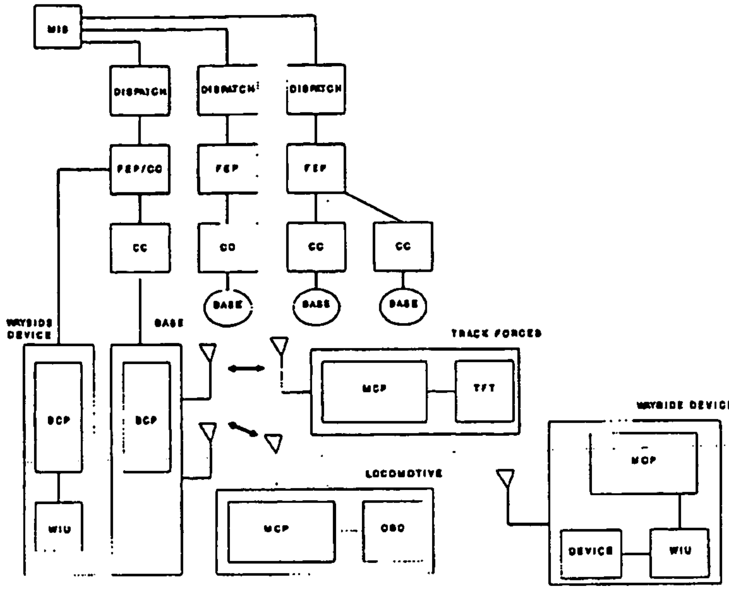

Fig. 2. ATCS Communication System.

The ATCS Communications System, illustrated in Fig. 2, consists of three major subnetworks. These are the following.

1) The *Ground Network* comprising the ground network nodes (comprised of front end processors, cluster controllers, and base communications packages) and the interconnecting communication lines (telephone circuits, microwave channels, fiber optic links, and modems).

2) The *Radio Frequency (RF) Network*, comprising the base communications package and mobile communications package radios and the RF channels on which they communicate.

3) The *User Networks*, which comprise the collections of objects and applications within each user (wayside device, locomotive or other vehicle and dispatch system).

B. Network Nodes

The *front end processor* (FEP) is the major entry point from a host computer into the ground network. It is normally connected to a number of cluster controllers.

The *cluster controller* (CC) is a routing node in the ATCS ground network. A CC would normally be connected to a number of radio base stations.

A FEP and CC's may be combined in a single unit (FEP/CC) which meets the requirements of both.

The *base communications package* (BCP) is a node in the ATCS ground network that provides an interface to the ATCS Radio Network. A BCP may contain a number of base station radios, operating on different channel pairs.

The *mobile communications package* (MCP) operates in locomotives, track force vehicles, and RF-connected wayside devices as the interface between the radio network and a locomotive computer or a wayside device. It can also be used in an optional configuration to interface wayside devices directly into the ground network without using the radio channel.

C. Network Branches

The nodes in the ATCS Communications Network are interconnected by data communication links. The relationship between the OSI model and the ATCS system components is shown in Fig. 3. Although the two end users in this case are a dispatcher and a locomotive, the communications between other pairs of users is similar.

Terrestrial links and on-board connections utilize common OSI protocols at the data link and physical layers, while an ATCS "busy-bit" protocol is used to achieve channel access in the radio network. An X.25-like ATCS Datagram protocol is used at the network layer; and, because of the special safety requirements, customized protocols have been developed at the transport, session, and application layers.

Flow control is exercised at two levels. Layer 2 flow control allows FEP's, CC's, BCP's, MCP's, and other user devices to stop accepting traffic for a short time when buffers are full. Layer 4 flow control enables end-to-end control.

Internal ground network interfaces, based on HDLC, are point-to-point or polled. Point-to-point is HDLC balanced, linking FEP, FEP/CC and CC. It implements FEP-FEP, CC-CC, FEP/CC-FEP/CC, FEP/CC-FEP, FEP-CC, CC-BCP and FEP/CC-BCP interfaces. The polled interface links CC and FEP/CC to base stations and, optionally, to wayside devices connected to the base station wireline. The polled protocol is a modified HDLC operating between BCP and CC.

Each RF channel consists of a pair of UHF channels. One is used for base to mobile-wayside communications on a non-contention basis, the other for mobile/wayside to base communications on a contention basis. Modulation is direct FSK at 4800 kb/s. The base station operates in full duplex on the RF network with separate transmit and receive channels; while

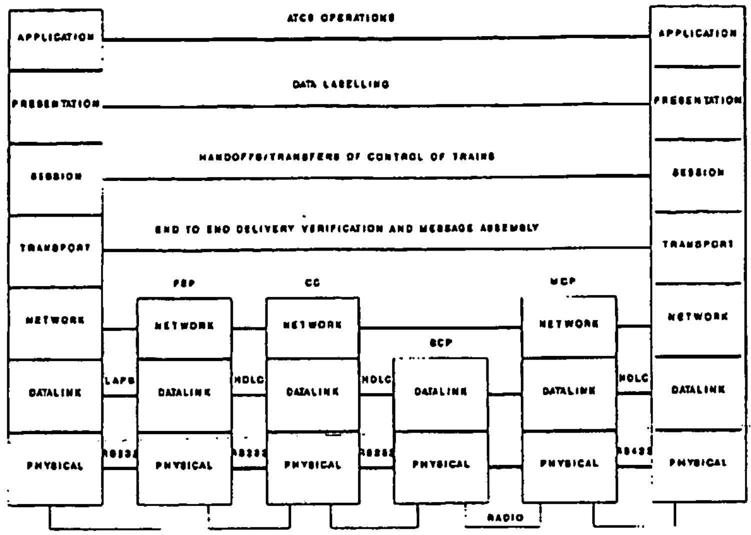

Fig. 3. OSI layers and ATCS system components.

the locomotive, track force and wayside devices operate on the complementary pair of channels in half duplex.

III. Nodes of the ATCS Communications System

A. The Front End Processor

The FEP is the interface between host computers and/or terminals and the ground data network. The entities within the FEP are as shown in Fig. 4, and are defined in ATCS Specification 220, Section 3.1 as:

1) vehicle following and packet routing;
2) ground user interface: layer 1-3 to ground based hosts and terminals;
3) ground network trunks: layer 1-2 to FEP's, CC's, and FEP/CC's;
4) network time updates;
5) flow control
6) buffering and queuing;
7) configuration;
8) failure/alarm reporting: either an attached printer or facility to send messages or both.

The FEP performs the following basic operations, defined in ATCS Specification 220, section 3.1.4:

1) power up self-test;
2) process traffic from ground trunks to stationary devices;
3) process traffic from ground trunks to vehicles/WIU's;
4) process traffic from vehicles and WIU's;
5) perform on-line health monitoring of manufacturer defined parameters.

The FEP routes packets based on routing tables and vehicle location tables. It implements buffering and prioritized queuing of packets, as well as flow control techniques. Blocked queues are cleared by a flow control recovery procedure described in Section IV-F-4. The FEP contains a mechanism for reporting on-line failures and faults and the status of itself and

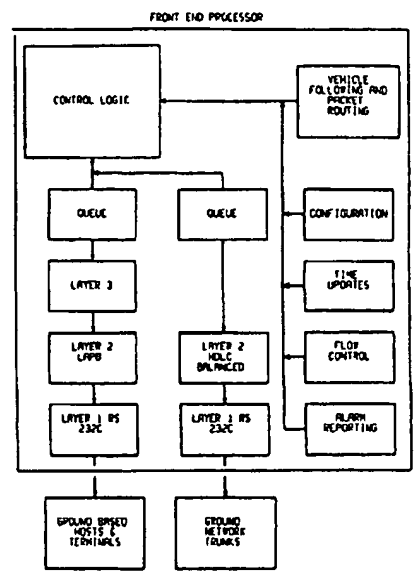

Fig. 4. FEP.

the communication lines. It is connected to its host/terminals and to other FEP's and CC's as shown in Fig. 5. The FEP provides layer 1, 2, and 3 interfaces to ground-based hosts and terminals; and layer 1 and 2 interfaces to other FEP's and CC's.

The FEP attempts to route packets to their destination. If it is unable to do so, it generates datagram service signals to inform the originator of the presence of a problem.

B. The Cluster Controller

The CC acts as the communications hub for a number of base stations. The entities within the CC are as shown in Fig.

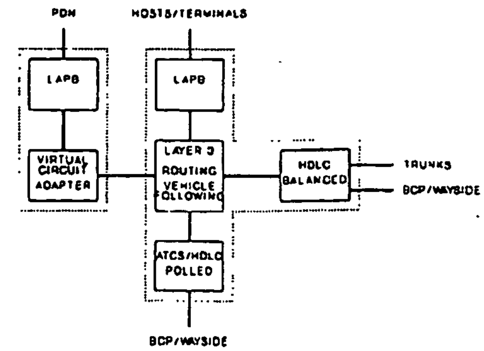

Fig. 5. FEP and CC connections.

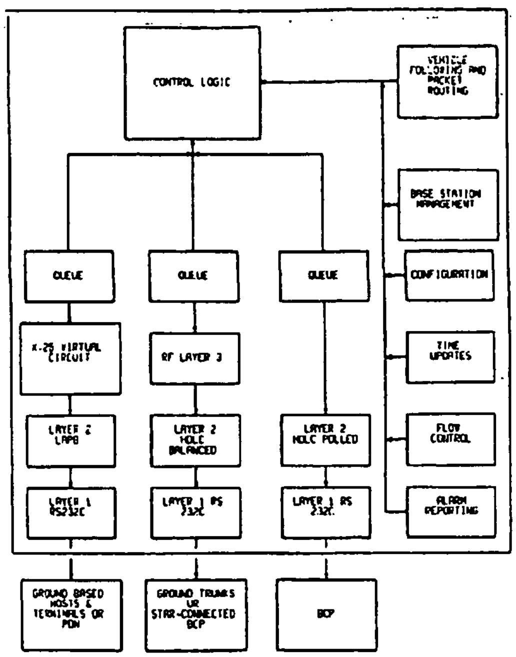

Fig. 6. CC.

6. The entities are defined in ATCS Specification 225, section 3.1.1 as:

1) base station management;
2) vehicle following and packet routing;
3) RF layer 3 protocol;
4) ground network trunks: layer 1-2 to FEP's, CC's, FEP/CC's, and BCP's;
5) network time updates;
6) flow control;
7) buffering and queuing;
8) configuration;
9) failure/alarm reporting: either an attached printer or facility to send messages or both. Reports CC, attached BCP, and communication line status.

The CC basic operations are defined in ATCS Specification 225, section 3.1.4 as:

1) power up self-test;
2) process traffic from trunks to stationary devices;
3) process traffic from trunks to vehicles/WIU's;
4) process traffic from vehicles/WIU's;
5) on-line health monitoring of manufacturer defined parameters.

Like the FEP, the CC routes packets based on routing tables and vehicle location tables, which must be maintained as the situation changes. It implements buffering and prioritized queuing of packets, as well as flow control techniques. The CC also contains a mechanism for reporting on-line failures and faults and the status of itself and the communication lines. The CC is connected to FEP's and CC's, and to BCP's, as shown in Fig. 5. The CC provides the RF Layer 3 protocol, and implements the Layer 1 and 2 interfaces to FEP's, FEP/CC's, CC's and BCP's. Connections to BCP's are normally operated with the ATCS/HDLC polled protocol, but may be optionally star-connected and use the HDLC Balanced protocol. The CC is also responsible for base station management in terms of directing tests of base stations and in exchanging traffic with them.

C. The Base Communications Package

The BCP is the interface between the ground network and the radio network. The entities within the BCP are as shown in Fig. 7. The entities are defined in ATCS Specification 230, section 3.1.1 as:

1) base station radio;
2) wireline interface;
3) local routing;
4) radio interface;
5) packet buffering and queuing;
6) self-test;
7) signal quality
8) receive channel health monitoring;
9) bufferless option: (this option may be implemented where the BCP and CC are manufactured by the same supplier, and the railroad does not require compatibility with other suppliers' CC's or BCP's).

The BCP contains one or more data radios and is connected to its controlling CC via the ATCS/HDLC Polled or HDLC Balanced Layer 2 protocols. The BCP implements the ATCS Radio Link data link layer protocol to communicate via UHF radio channels with locomotives and track forces within its coverage area.

Emergency traffic received on in-bound channels is relayed immediately to all out-bound channels.

The BCP is capable of performing a self-test upon command and reporting the results of the test. The test includes software integrity and radio status.

The BCP monitors all received radio signals and continuously reports the signal levels to the controlling CC. Alarm messages are sent when the BCP detects carrier with no data for greater than 1.5 s and when a MCP is detected transmitting for longer than 10 s.

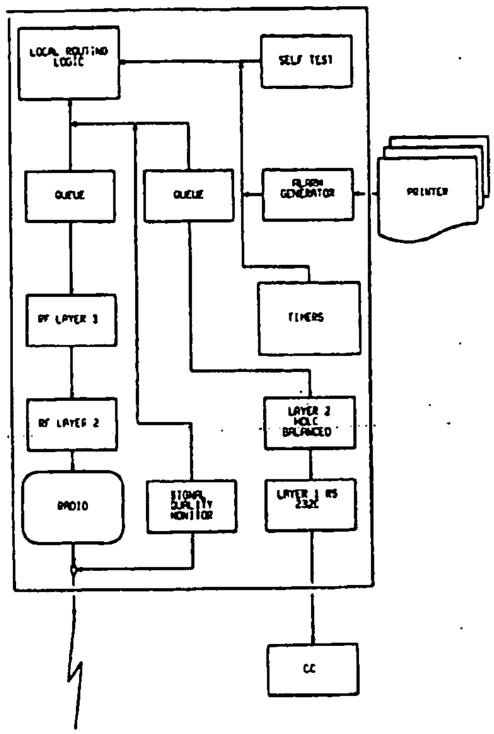

Fig. 7. BCP.

D. The Mobile Communications Package

The MCP is the interface between the radio network and locomotive computers, intelligent terminals, and wayside devices. The entities within the MCP are as shown in Fig. 8. The entities are defined in ATCS Specification 210, section 3.1, as:

1) frequency controller;
2) radio network layer 3 protocol entity;
3) local routing logic;
4) layer 2 (HDLC Balanced) protocol entity;
5) layer 2 (RF network) protocol entity;
6) layer 1 (RS 422) interface;
7) radio;
8) packet buffering and queuing;
9) self-test;
10) in coverage contact timer.

The MCP contains a frequency controller, local routing logic, and the means to buffer packets to and from the radio, the frequency controller, and its "client" interface. The MCP is connected to the radio network via a data radio. It implements the ATCS radio network layer 3 datagram protocol and the radio link layer 2 protocol. The MCP is connected to its "clients" via an HDLC/RS 422 interface. The MCP operates in a number of modes: power up, in which a self-test is automatically performed; normal operation, in which traffic is processed routinely; impaired operation, in which the MCP rejects all traffic; and disabled operation, in which the MCP refrains from transmitting; flow control, in which the MCP clears its buffers; and out-of-coverage, in which the MCP interacts directly with wayside devices.

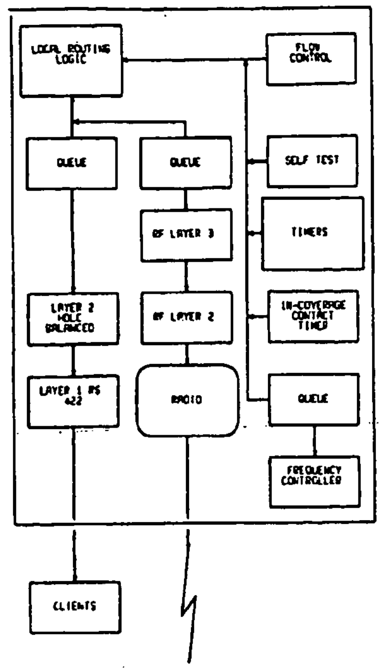

Fig. 8. MCP.

IV. Protocols in the ATCS Communications System

A. Upper Layers

1) The Application and Presentation Layers: The ATCS application layer protocol provides the bridge between the applications program and the ATCS data communications system. It provides the mechanism that allows an application to open and close communications sessions, to be informed of the state of those sessions and to send and receive data on those sessions. Unique features of the ATCS application layer include the special handling of emergency messages.

2) Session Layer: The ATCS session layer protocol provides the services necessary to ensure that only data in appropriate formats are provided to applications. In the ATCS system it is also responsible for assigning priority, class of service to send traffic, for flagging traffic as *vital* (life threatening) or nonvital, and for ensuring that vital data are not carried in a nonvital mode.

The session layer provides the mechanism that controls the association and disassociation of applications that must cooperate to perform their functions. There are three types of sessions in the ATCS network. They are: the general purpose session (mandatory for all ATCS communication system users), the master session (mandatory for all users who control other users, and the slave session (mandatory for all users who

are controlled by other users). Sessions are controlled (opened and closed) by a defined set of signals and control messages.

3) Transport Layer: The ATCS transport layer provides the services of message segmenting and reassembly, duplicate elimination, vital message integrity checking, end-to-end acknowledgment, and handling of priority traffic. The transport layer depends upon certain fields in the message packet headers to determine the way in which it will handle messages. Procedures are defined to describe the way in which received service signals and message packets are treated. Layer 4 may originate traffic, and interprets the following transmission modes: broadcast, normal, data base, assurance, and special emergency broadcast. The transport layer is capable of end-to-end acknowledgment as well and selective nonacknowledgment, receiver abort, receiver reject, transmitter abort, and receiver delay request (which causes message queuing in various nodes). Layer 4 maintains timers that monitor end-to-end acknowledgments. Finally, the transport layer imposes a redundancy check code (32-b CRC) on vital messages.

B. Layer 3: Datagram Packets

1) Ground Network Protocol: As introduced in Section I-E, information is transmitted through the ATCS Communications System in packets in a datagram mode. That is, information is transmitted in independent packets, or *datagrams*, rather than in a virtual circuit mode. The information is communicated as either *messages* or *service signals*, and they have different packet formats. Service signals are used for the communication of information relevant to the communication system, while message packets carry operational information.

2) Radio Network: The layer 3 radio network protocol is responsible for controlling the transfer of packets across the radio network. Layer 3 entities maintain a prioritized queue through which packets are passed to layer 2 entities for transmission.

Traffic is controlled on the RF link by channel group. Traffic on odd numbered channels is sent without acknowledgment, and traffic on even numbered channels is sent with the expectation of acknowledgment. In exchanges of traffic on even numbered channel groups between the ground network and RF users, a maximum of one unacknowledged packet may be outstanding. Layer 3 procedures are defined for the transfer of unacknowledged traffic and the exchange of acknowledged traffic between the ground network and RF users, and between RF users. Procedures are defined for generation of acknowledgments, and the operation of the RF network in a polled mode.

C. Lower Layers in the Ground Network

Communications between ground host and terminal users and FEP's, CC's, and FEP/CC's are governed by the LAPB data link protocol, as defined by CCITT Recommendation X.25 Section 2.

Communications between FEP's, FEP/CC's and CC's, and between OBC's and the MCP are governed at the data link layer by the HDLC Balanced protocol, class BAC 1A, 2, 4 as defined in ISO specification 6256. On-board link layer addresses are defined, for use in the XID identification process. Frame lengths and timer limits are defined; up to seven outstanding information frames are permitted.

Communications between CC's (or FEP/CC's) and the BCP is an adaptation of HDLC called the ATCS/HDLC Polled Protocol. The CC (or FEP/CC) implements the master side of the protocol while one or more BCP's may be attached to the line to implement the slave side of the protocol.

The protocol allows for information, self-test command, poll, and reset command frames to be sent from the master to the slave; and for information, self-test performance, self-test request, receive ready (RR), and receive not ready (RNR) frames to be sent from the slave to the master.

The default physical layer interface for the ATCS ground network is EIA RS 232C, although RS 422 may be used optionally. The default data rate for these data links is 9.6 kb/s, with 4.8, 19.2 and 56 kb/s as options.

D. The Radio Data Link Layer

Data are transmitted on the RF link in frames and blocks. The radio data link layer protocol is used between wayside/mobile users and base stations in coverage areas and between wayside and mobile users in "dark" territory.

Packets received from the radio network layer 3 protocol are segmented into frames containing a 40-b frame synchronization sequence (07092A446F hex), the destination address, a pad count indicating the number of 0's added to the information field, a length field indicating the number of blocks required to hold the frame, a header CRC field, an information field which can hold a datagram packet, a pad field, and an information CRC. Both CRC's are calculated according to the polynomial $G(x) = x^{16} + x^{12} + x^5 + 1$.

The frame is segmented into blocks of 60 b with the last block padded with zeros to make its length exactly 60 b. Each block is FEC encoded for transmission using a Reed-Solomon (16,12) code, resulting in a block length of 80 b. Five "busy bits" are added to the encoded block before transmission. The busy bits are inserted in the encoded bits, i.e., between bits 15-16, 30-31, 45-46, 60-61, and 75-76. The busy bits reflect the state of the inbound channel at transmission time. When it is transmitting, the BCP sets the busy bits to 0 if the receive (inbound) channel is idle, and to 1 if it is receiving inbound radio traffic. The MCP always transmits with the busy bits set to 1.

An MCP accesses the channel by monitoring the state of the channel. If the channel is free (no base station carrier) the channel is accessed. If the MCP receives sync patterns, a random delay is introduced, and the state is remonitored. If data are received and the last three busy bits are set to 0, the channel is accessed; otherwise the channel is remonitored after a random delay.

When a block is received the busy bits are removed and an error correction algorithm applied. The first 40 b of the first decoded block are checked for a valid header CRC. If it is correct, subsequent blocks are decoded as specified by the length field; and the received data are passed to the frame decoder. If the packet CRC is bad, the packet is discarded.

E. The Radio Signals

The ATCS radio network consists of pairs of UHF channels. The channels are in the 896/935 MHz band.

The data radios operate on a pair of channels (BCP in full duplex, MCP in half-duplex) at 4800 b/s. The method of modulation is baseband filtered frequency shift keying. The Gaussian filter has a time bandwidth product of 0.5, and the frequency deviation is +-1.7 kHz.

F. Special Features

1) Maintenance of Vehicle Following Tables: Each routing node (FEP, FEP/CC or CC) in the network must maintain tables containing a list of other routing nodes and the paths to those nodes; a list of stationary users for whom the node is the controlling node and how to pass packets to those users; and a vehicle following table: a list of vehicles and the identity of their controlling node. For vehicles controlled by the node, the table contains the information necessary to get packets to that vehicle (which base to use). The routing tables are configured from the ground network, the vehicle following tables are created and maintained dynamically. The latter are automatically purged every 10 min of all unused entries.

When a node receives a message for a vehicle that is unknown, it sends a search message to all other nodes. When this message is received by the node that controls the unknown vehicle, it transmits a notification message to all nodes. The same thing happens when a node first receives a message from a vehicle over which it did not previously have control.

2) Network Time Updates: The dispatch safety system maintains a master clock and disseminates the time to all elements under its control by broadcasting time update messages at least once every hour. Time update messages are also transmitted in response to time query messages, which may be used a means for elements to check the system integrity. Medium and low priority traffic through ground network nodes is suspended (and queued) for 5 s whenever a network time update warning message is received. This ensures that network time update messages will be transmitted without delay through the network.

3) Priority Traffic and Prioritized Queues: ATCS traffic is divided into eight priority levels. All traffic is buffered and queued in prioritized queues. Top priority is given to emergency, time critical, and operational traffic. Normal traffic and long messages are given lower priority but have assured access to the communications network; history data has the lowest priority.

4) Flow Control Recovery: When a node has been in flow control at layer 2 for 5 s, it begins discarding traffic from its queues, lowest priority first, with the exception of emergency traffic. If this process does not result in the termination of flow control within 10 s, the node declares a major failure and discards all traffic. If the node remains in flow control after this, a power-up reset is attempted or the node switches to a standby processor, if one is available.

V. Summary

The ATCS, and particularly the ATCS Communications System, represents a major application of modern communications systems design principles. It is based on the open system concept and provides manufacturers with the maximum amount of freedom to exercise their ingenuity in realizing any one of the entities, while assuring them (and the railroads) that entities manufactured to ATCS Specifications will have a market, and the system incorporating them will perform as required with improved efficiency, safety, and economics.

Acknowledgment

The ATCS plan is the result of efforts by a large number of persons and organizations. The authors are privileged to have had the opportunity to work with them and to present the results of their work.

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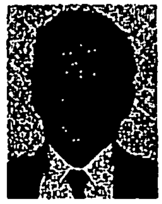

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Analytical Model for ATCS Inbound RF Channel Throughput

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Abstract — An analytical model has been developed to analyze the throughput of the Advanced Train Control System (ATCS) inbound RF channel for a finite number of mobiles. The inbound channel access protocol is a special version of Carrier Sense Multiple Access (CSMA) protocol. The model is intended to provide an analytical method of predicting the effect of packet collisions and retries on inbound RF channel throughput.

I. Introduction

The Advanced Train Control System (ATCS) [1-3] is a concept developed by North American Railroads working through the Association of American Railroads and Railway Association of Canada. ATCS is intended to provide for safer railroad operation by linking a central dispatching and safety computer with computers on locomotives and controlling wayside switches. The locomotive computer is equipped to stop the locomotive before a stored movement authority can be exceeded. The central safety computer communicates with wayside and locomotive computers over an RF data link.

The ATCS RF link operates on pairs of RF channels in the 900 MHz band. One channel is used for inbound (from the locomotive to the base) transmission. The other channel is used for outbound (from the base to the locomotive) transmission. The baud rate is 4800 bits per second.

The access method for the inbound channel is a CSMA-type protocol. This adds an overhead of retries for the collided packets in the channel load. The basic measure for the efficiency of an RF protocol (and in general for CSMA-type protocols) is throughput, i.e., the average fraction of time that the channel is used for useful data communication. Three factors accounting for the throughput degradation are propagation delay, mobile's idle period, and packet collision.

A number of studies have been published on the throughput analysis of CSMA-type protocols [4]. However, most of them have been based on the assumption of infinite nodes. This type of population provides collective channel traffic which forms Poisson process with a finite rate.

In the ATCS system, a finite number of locomotives may operate in the coverage of a base station. For this reason, it is more appropriate to analyze the throughput of the inbound RF channel analytically by assuming a finite population of mobiles. The model developed for analyzing the throughput of an ATCS inbound RF channel for a finite number of mobiles is the topic of this paper.

II. RF Channel Access Protocol

With the ATCS data radio network, messages to be sent over the radio channel are separated into packets. Each packet is addressed with source

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and destination information before transmission. Successful delivery of a packet is verified by receipt of an acknowledgment from the destination. Depending upon the mode selected for transmission, acknowledgments will be sent either for an individual packet (mode 1) or for a group of packets (mode 2).

A mobile radio system is subject to noise and fading conditions which can result in data errors. Forward Error Correction (FEC) is used over the radio link to recover from errors during transmission. The FEC code used is a Reed-Solomon which adds bits for error detection and correction to every block of data. Messages to be transmitted are separated into 60-bit blocks. Each 60-bit block becomes 80 bits long when the FEC bits are added. This 80-bit block of data encoded with FEC provides the basic structure for all ATCS RF data traffic.

In its most simple form, the RF link consists of a single base station communicating with a number of mobiles. In actual operation there may be more than one base station involved in the link to a mobile. The base station transmits on one RF frequency and receives on a different RF frequency. The base station is full-duplex equipment while the mobiles and wayside equipment are half-duplex. The inbound traffic received by a base station is characterized by random transmissions from a number of locomotives and other mobiles of the RF link. Mobiles can't hear each other but they all hear the base. To minimize the inbound collisions, the base station is used to inform the mobiles when inbound traffic can be sent.

In order to provide a method for managing inbound channel access, additional bits called "busy bits" are added to the 80-bit data block described above. For every 15 bits, an extra bit is added, making a total block of 85 bits. When a mobile transmits, the busy bits are all set. At the base station, the busy bits in the outbound data stream reflect the status of the inbound channel. If the bit is set, the channel is busy. If the bit is reset, then the channel is idle.

When a base station is transmitting data outbound, it will insert busy bits in the data stream upon receipt of inbound traffic. These busy bits are monitored by the other mobiles wanting to use the channel. When a mobile checks the channel and finds that some or all of the last 3 busy bits were set, it will wait a random time from 10 to 2000 ms before checking the channel again. If the mobile finds the last 3 bits set to idle when it checks the channel, it will access the channel. If a synchronous pattern is detected, the mobile will wait a random period between 10 and 800 ms and then check the channel again. If fewer than three busy bits have been received since the synchronous pattern, the mobile will wait a random period between 10 and 50 ms and check the channel again.

III. Model Description

An analytical model described below has been developed for the throughput analysis of the RF inbound channel with a finite number of mobiles. This model is based on the assumption that each mobile has independent periods of time in which the mobile has no packets to send. By superimposing these idle periods over all mobiles, the system's idle period is exponentially or geometrically distributed. This makes the system more manageable by using the memoryless property [5, p. 66]. This assumption was not made for the infinite population case due to the Palm-Khinchine theorem [6].

Packet lengths are assumed to be constant (251-byte data) and equal to X, and packet transmission time is X/R (R baud rate); for convenience X/R was denoted as P. The vulnerability window which determines how many inbound collisions will occur on the channel, is denoted by "a". "a" is determined based on tp/P where tp is:

$$t_p = t_{mb} + t_{bs} + t_{bz} + t_{bm} + t_{ms} + t_{pt}$$

where

- t_{mb}: Mobile to base station propagation delay
- t_{bs}: Base station bit synchronization
- t_{bz}: Base station busy bit insertion
- t_{bm}: Base station to mobile propagation delay
- t_{ms}: Mobile serial communication delay
- t_{pt}: Mobile communication delay (PTT)

The model developed is capable of providing a throughput analysis of a finite number of mobiles and a single base station in line-of-sight of all mobiles. The model also assumes acknowledgement packets are always correctly received and the base station is configured to access the outbound channel continuously.

A Relationship between S, normalized throughput with respect to P, and G, the normalized total offered load including the retries can be obtained by considering time as consisting of cycles of alternating busy and idle periods. A cycle ends with an idle period during which no mobile is attempting to transmit. The cycle is initiated by arrival of a packet to some mobile following an idle period. A cycle containing multiple transmissions is illustrated in Figure 1.

In Figure 1, the packet initiating the cycle is denoted by packet 0. In steady-state, all cycles are statically similar; thus throughput can be determined as the ratio of the average amount of time devoted to successful transmission during a cycle, to the average total length of the cycle. Denoting the average duration of the time devoted to successful transmission as U, the average length of the idle time period as I, and the average length of the busy time period as B, S can be expressed as:

$$S = \frac{\overline{U}}{\overline{B}+\overline{I}} \qquad (1)$$

Where X denotes the expectation of the random variable X.

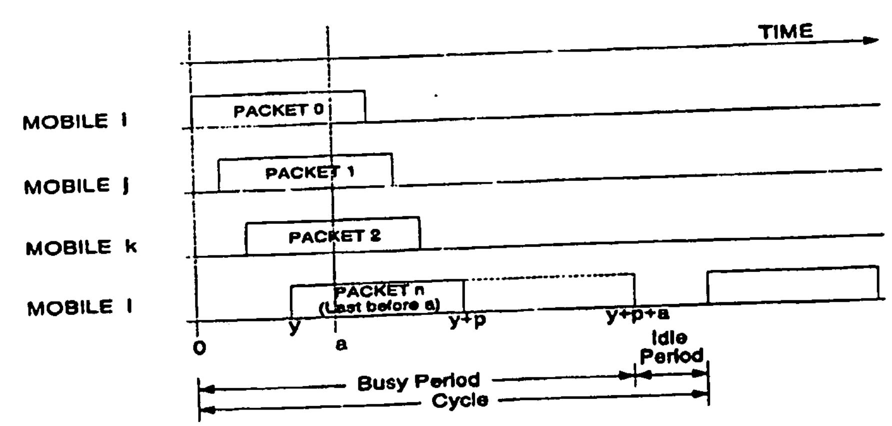

Figure 1. Inbound RF Channel State

Upon the arrival of a packet, the network enters the "busy" time period. The busy period terminates at the end of a transmission period in which no packets have arrived.

A channel busy period is divided into a number of successive sub-busy periods, each consisting of a transmission delay followed by transmission time. The transmission delay is the time during which the channel is idle but some packets are awaiting transmission. If a transmission is successful, its duration is $1 + a$. If a transmission is unsuccessful, its duration is $1 + a + Y$, where Y is the transmission start time of the last colliding packet. Note that the jth sub-period, $j \geq 2$, is generated by the packets which arrive during $1 + Y$ in the $(j-1)^{st}$ sub-period, whereas the first sub-period is always generated by one packet. Let Bn be the mean duration of the busy period initiated by n packets, and let Un be the mean number of successful transmissions in the same busy period. Also, if it is assumed that the time until a packet arrives at each of the empty mobiles is independent and exponentially distributed with mean $1/g$. Then,

$$\overline{B} = B1; \quad \overline{U} = U1.$$

since

$$I = \frac{1}{gM}$$

then (1) for M mobiles gives

$$S = \frac{U1}{B1 + \frac{1}{gM}} \tag{2}$$

Now if a system of linear equations is derived for

$$\{Bn;\ n = 1, 2, \ldots, M\}$$
$$\text{and}$$
$$\{Un;\ n = 1, 2, \ldots, M\}$$

then S is obtained.

Next, a sub-busy period that begins with n packets is considered. Taking the origin of the time at the start of this sub-period, let $N(x)$ be the number of packets present in the system at time x. The distribution of the transmission delay denoted by R on the condition that $N(0) = n$ is first considered. Each of n busy mobiles schedules his transmission after time x with a probability of PR.

Consider the event

$$\{R > x,\ N(x) = n + m \mid N(0) = n\}$$
$$\text{where } PR = e^{-px}.$$

where m is the number of arrivals during R. For this event to occur, each of the M-n-m mobiles does not have an arrival before x with a probability of PG. For each of m mobiles, the time until arrival plus start of transmission is less than x, with a probability of

$$\int_0^x ge^{-gz} \cdot e^{-P(x-z)}\, dz = \frac{g}{p-g}\left(e^{-gx} - e^{-px}\right) \tag{3}$$
$$\text{where } PG = e^{-gx}.$$

Thus,

$$Prob[R > x,\ N(x) = n+m \mid N(0) = n] \tag{4}$$
$$= e^{-pxn}\binom{M-n}{m} e^{-gx(M-n-m)}\left[\frac{g\left(e^{-gx} - e^{-px}\right)}{p-g}\right]^m$$
$$X \geq 0 \quad m = 0, 1, 2, \ldots, M-n.$$

Adding (4) over all m

$$Prob\ [R > x \mid N(0) = n] \tag{5}$$
$$= e^{-pxn}\left(\frac{pe^{-gx} - ge^{-gx}}{p-g}\right)^{M-n}$$
$$x \geq 0$$

so that the mean transmission delay conditioned on $N(0)=n$ is given by

$$E[R_{(n)}] \triangleq E[R|N(0)=n] \qquad (6)$$
$$=\int_0^\infty e^{-pnx}\cdot\left(\frac{pe^{-gx}-ge^{-px}}{p-g}\right)^{M-n} dx$$
$$n=1,2,\ldots,M$$

The behavior of M-1 mobiles in the transmission period following the transmission delay is next considered, so that $R=x$ and $N(x)=n+m$. During the first a time units, each mobile behaves independently. Each of $n+m-1$ (which has packets to transmit) mobiles either does not start transmission before a, with a probability of PA, or starts transmission before y with a probability of PY. There are three cases of behavior for each of the M-n-m mobiles who were empty at the end of R:

i) no arrival during a with probability e

ii) arrival before a, but transmission after a, with probability

$$\frac{g(e^{-ga}-e^{-pa})}{(p-g)}$$
$$PA=e^{-pa}$$
$$PY=1-e^{-py}$$

iii) arrival and transmission before y, with probability

$$\int_0^y ge^{-gz}[1-e^{-p(y-z)}]\,dz$$
$$=1-\frac{pe^{-gy}-ge^{-py}}{p-g}$$

Therefore

$$Prob[Y\le y|R=x,N(x)=n+m,N(0)=n] \quad (7)$$
$$=(1-e^{-py}+e^{-pa})^{n+m-1}$$
$$\cdot\left[\frac{p(1-e^{-gy}+e^{-ga})-g(1-e^{-py}+e^{-pa})}{p-g}\right]^{M-n-m}$$
$$0\le y\le a$$

is the probability of a successful transmission. Unconditioning (7) on N(R) and R, using (4) and (5) successively, gives:

$$f(y;n)\triangleq Prob[Y\le y|N(0)=n]$$
$$=(1-e^{-py}+e^{-pa})^{n-1}$$
$$\cdot\left[\frac{p(1-e^{-gy}+e^{-ga})-g(1-e^{-py}+e^{-pa})}{p-g}\right]^{M-n}$$
$$n=1,2,M$$
$$0\le y\le a$$

and similar unconditioning for the probability of a successful tranmission yields

$$\gamma_n\triangleq f(0;n)=e^{-pa(n-1)}\left(\frac{pe^{-ga}-ge^{-pa}}{p-g}\right)^{M-n}$$
$$n=1,2,\ldots,M$$

Note γ that is the probability of success in the sub-period begun with n packets. The mean of Y in the similar sub-period is given by

$$E[Y_{(n)}]\triangleq E[y\,|\,N(0)=n]$$
$$=a-\int_0^a f(y;n)\,dy$$
$$n=1,2,\ldots,M.$$

Finally, the condition has K accumulated packets at the end of the transmission period is considered. If the duration of the transmission period is $1 + a + y$, those packets which arrive during $1 + y$ are buffered. Therefore, the probability of having K packets in the transmission period of duration $1 + a + y$ is given by $g_k(1 + y)$, where:

$$g_k(y) \triangleq \binom{M}{K} (1-e^{-gy})^k e^{-gy(M-K)}$$

$$K = 1, 2, \ldots, M$$

By similar unconditioning, the probability p_{nk} that the next sub-period begins with k packets is written as:

$$P_{nk} = g_k(1)\, f(0;n) + \int_0^a g_k(1+y)\, dy\, f(y;n)$$

where $f(y;n)$ is given by (8).
Now a set of equation for Bn and Un can be concluded:

$$B_n = E[R_{(n)}] + 1 + a + E[Y_{(n)}] + \sum_{K=1}^{M} B_k P_{nk}$$

$$n = 1, 2, \ldots, M$$

and

$$U_n = Y_n + \sum_{K=1}^{M} U_k P_{nk} \quad n = 1, 2, \ldots, M$$

Thus, the throughput can be computed from substitution of $B1$ and $U1$ into (2).

IV. Results

The prediction of the inbound RF channel throughput by the developed model for a number of mobiles is plotted. Figure 2 illustrates the throughput versus the offered load (normal load plus the retried overhead) for different numbers of mobiles (M). The throughput prediction plot shows that as the number of mobiles increases, the maximum throughput decreases. However, for a small number of mobiles (M $\leq$ 10), the throughput decrease is more noticeable than for a large number of mobiles. The throughput variation for large numbers of mobiles is almost null.

The results of actual testing performed with four mobiles at the Automated Monitoring and Control International, Inc. (AMCI) laboratory is plotted

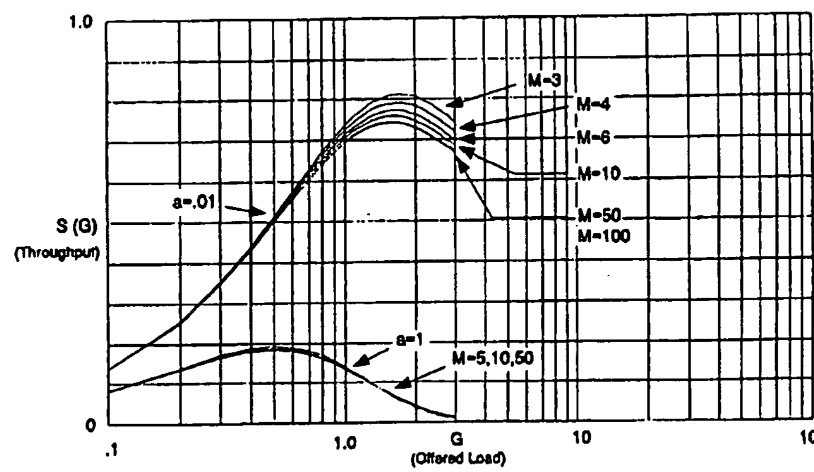

Figure 2. Model Throughput Predictions for Inbound RF Channel

in Figure 3. By comparing the results of the laboratory testing to the results of the analytical model, one can observe that the model prediction throughput is higher than the laboratory data for the smaller load. However, as the load increases, the model prediction is much closer to the laboratory data.

V. Model Verification

Several test configurations with different numbers of mobiles were set up at the AMCI laboratory to evaluate the accuracy of the predictions of the described model. The laboratory test configuration consisted of locomotive computers known as On Board Terminals (OBT), Mobile Communication Packages (MCP) where the connections between the OBT and RF channels were set up, a test fixture for the RF channel emulation, and the Base Communication Package (BCP) which provided base station functions.

Four mobiles were configured to communicate with a base station through a test fixture in AMCI laboratory. Each mobile was set up to transmit packets randomly in a time frame in which the upper and lower random delays were defined. Also, different message sizes (different packet numbers in a message) and different sessions were used to control the offered load to the channel.

As mentioned, Figure 3 shows the results of laboratory testing collected data and the predicted throughput from the analytical model for the same environmental variable values. As can be observed, the throughput predicted differs by about 12% from collected data in the laboratory testing. It is believed that the different sources such as precision in data collection in the laboratory, and test fixture emulation of the RF channel are the contributing factors to the difference.

Summary

An analytical model for throughput analysis of the ATCS inbound RF channel is presented for a finite number of mobiles. The model is based on a special case of the CSMA protocol. The accu-

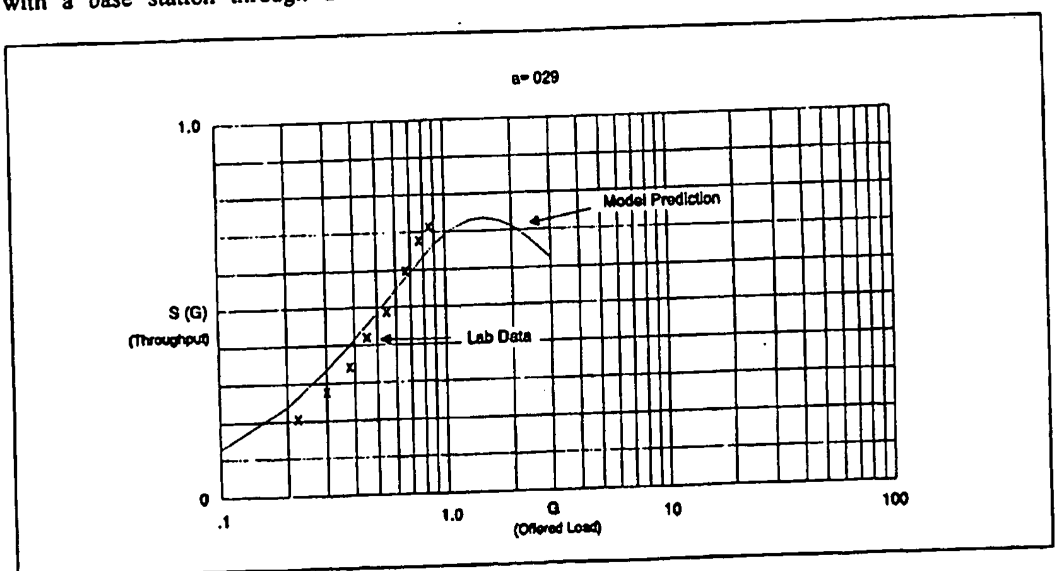

Figure 3. Throughput of Inbound RF Channel (a = .029)RF Channel

racy of the model's predicted throughput data was verified at the AMCI laboratory where similar results were obtained through actual testing. Thus, an accurate prediction of the inbound RF channel throughput for different offered loads in the ATCS environment can be provided.

A best-case assumption for this model presumes:

i) a base station in line of sight of all mobiles,
ii) no overlapping radio coverage, and
iii) acknowledgment packets are always correctly received.

The model shows that maximum throughput values are not always dependent on the number of mobiles as long as the number of mobiles is reasonably large. It also demonstrates that the throughput of large numbers of mobiles quickly degrades with congested traffic (large load), while the throughput of a network containing a small number of mobiles does not degrade as fast.

The ATCS RF inbound throughput analysis based on the model described here shows sufficient capacity to address the current and future needs of ATCS data communication traffic. The channel access mechanism has been found to be well suited for a wide range of numbers of mobiles (small or large) that support high throughput. The throughput is mainly a function of the collision window "a" which is reasonably small in the ATCS' field. Indeed, the retransmission load due to packet collisions does not greatly reduce the channel capacity. This is due to the implementation of the "busy bits" and the full-duplex operation of the base stations.

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